Preliminary Interference Assessment and Potential Mitigation Techniques for NGSO EESS Congestion in the 8025-8400 MHz Band

presented by Ted Berman – ITT Industries

International EES Wideband Downlink Workshop
March 25-27, 2003
Orlando, Florida, USA

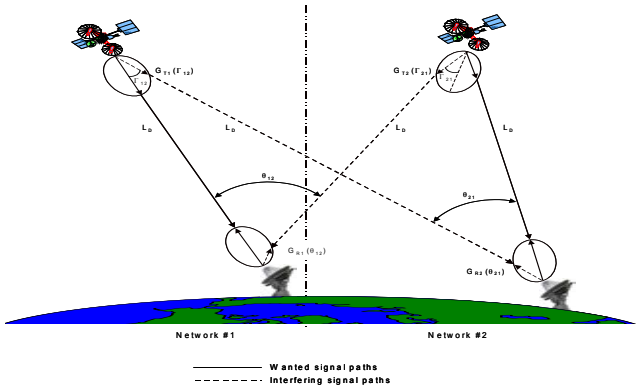
Introduction

- **Paper presents the results of an analysis to determine the interference statistics of a set of operational and planned NGSO EESS satellite networks under a set of worst-case situations**
  - **i.e., no practical technical or operational mitigation techniques were used to minimize inter-system interference**
- **Key part of the analysis is the examination of a potential strategy for interference mitigation: homogeneity of satellite networks parameters**
- **Four sets of analyses were performed**
  - **The baseline set contained the least homogeneous parameters**
  - **Each subsequent set increased the level of homogeneity relative to the previous one**

The Interference Model

- The figure below illustrates a specific sharing situation concerning space-to-Earth links of two networks of a more general deployment of n networks
- The aggregate interference power received, in W/Hz, is given by

$$I_j(f) = A_{iso}(f) \sum_{i=1, i \neq j}^{n} PFD_i(f, el_{ij}) G_{Rj}(\theta_{ij})$$



Characteristics of Interfering EESS Missions

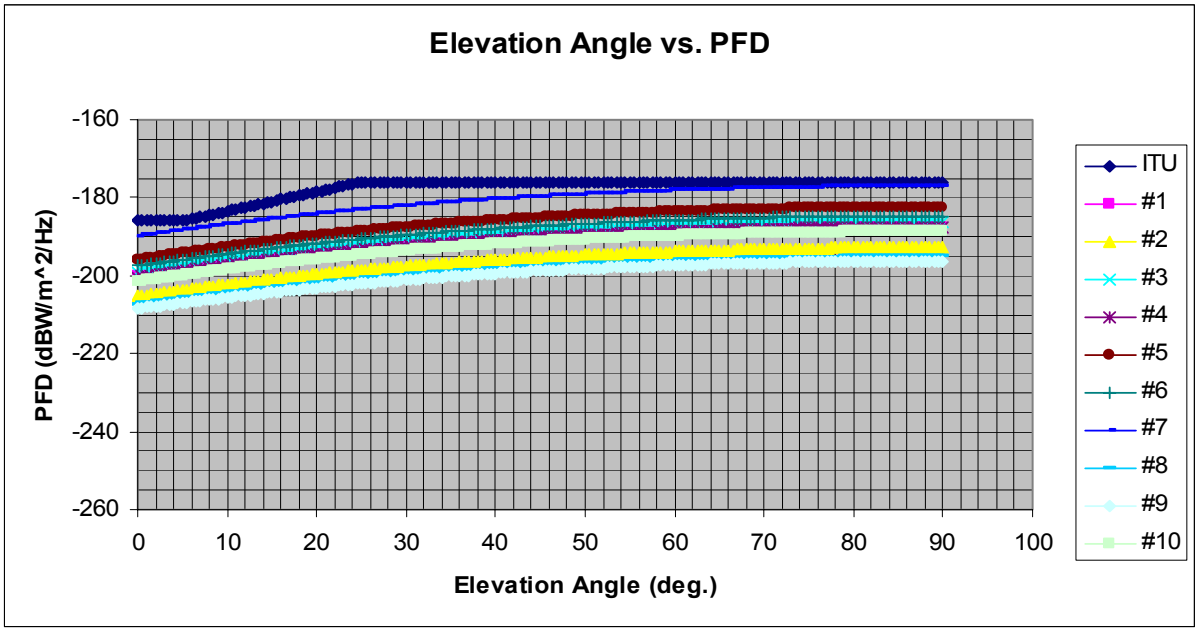
- An extensive search of existing and planned NASA and other US Government missions in the 8025-8400 MHz band has been performed
- Based on information found in the Space Frequency Coordination Group (SFCG) database and the ITU SNS database
- Analysis assumes that all missions operate co-frequency

Mission Name	Mission Number	EIRP Density (dBW/Hz)	Apogee (km)	Perigee (km)	Inclination (deg.)	Right Ascending Node (deg.)
CALIPSO	1	-59.5	705.0	705.0	98.08	204.75
TERRA	2	-64.2	714.0	697.0	98.2	337.5
AURA	3	-58.3	705.0	705.0	98.2	204.5
AQUA	4	-59.6	705.0	705.0	98.2	202.5
ICESAT	5	-56.0	602.4	584.3	94.0	0
LANDSAT-7	6	-56.7	705.0	705.0	98.2	330
EO-1	7	-49.1	705.0	705.0	98.2	330.25
NPP	8	-65.8	824.0	824.0	98.2	337.5
CORIOLIS	9	-66.9	830.0	830.0	98.7	0
SAC-C	10	-60.7	705.0	700.0	98.29	333.75

PFD Limits

- **ITU PFD Limits in 8025-8400 MHz band, Table 21-4 in Article 21, expressed in 1 Hz band**
  - **-186 dBW/m^2/Hz,** $\theta \leq 5^o$
  - **-176+(θ-5)/2 dBW/m^2/Hz,** $5^o \leq \theta \leq 25^o$
  - **-176 dBW/m^2/Hz,** $\theta \geq 25^o$

- **PFD Values for each mission are shown below**
  - **Are lower than ITU limit, by up to 20 dB**



Characteristics of Victim EESS Missions

- Victim EESS missions are taken from the population of interfering EESS missions discussed above
- A separate analysis is done using each of the 10 missions as a victim being interfered with by the other 9 missions
- Antennas modeled by Annex III, Appendix 8 of the ITU Radio Regulations

Mission Name	Mission Number	ES Name	ES Latitude	ES Longitude	ES Antenna Gain (dBi)
CALIPSO	1	Fairbanks, AK	64.8°N	147.5°W	59.3
TERRA	2	Poker Flats, AK	65.1°N	147.5°W	57.5
AURA	3	Poker Flats, AK	65.1°N	147.5°W	57.5
AQUA	4	Poker Flats, AK	65.1°N	147.5°W	57.5
ICESAT	5	Poker Flats, AK	65.1°N	147.5°W	57.5
LANDSAT-7	6	Poker Flats, AK	65.1°N	147.5°W	57.6
EO-1	7	Poker Flats, AK	65.1°N	147.5°W	56.5
NPP	8	Svalbard, Norway	78.2°N	15.4°E	57.8
CORIOLIS	9	Fairbanks, AK	64.8°N	147.5°W	59.3
SAC-C	10	Falda Del Carmen	31.5°S	64.5°W	54.9

Allowable Levels of Interference

- **Recommendation ITU-R SA.1026-3 provides the interference criteria in the 8025 – 8400 MHz band (this formulation of the recommended interference criteria ignores the reference bandwidth)**
  - **I_0 not to exceed -197 dBW/Hz more than 0.025% of the time**
  - **I_0 not to exceed -201 dBW/Hz more than 0.25% of the time**
  - **I_0 not to exceed -207 dBW/Hz more than 20% of the time**

PFD of Each Mission at Elevation Angle = 5°

- Some analysis cases make use of homogeneous PFD values
- Based on adjusting database PFD values
- Database values at elevation angle = 5° shown below

	ITU	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
PFD (dBW/m^2/Hz)	-186.0	-198.7	-203.8	-197.5	-198.8	-194.3	-195.9	-188.3	-205.8	-207.0	-199.9
rel to mean (dB)	13.0	0.3	-4.8	1.5	0.2	4.7	3.1	10.7	-6.8	-8.0	-0.9

Analyses: 4 Cases

- **Case A: Baseline case**
  - EIRP Density as given in database
  - Interferer transmit antennas are isotropic
  - Victim receive antenna gains as given in database
  - Transmit whenever in view of mission ground stations
- **Case B: Same as Case A, except that**
  - EIRP Density of each mission is adjusted so that the PFD level is equal to –199.0 dBW/m^2/Hz at an elevation angle of 5.0°. To achieve this, the EIRP density level is adjusted by the amount shown in table above: e.g., for mission #1, it is decreased by 0.3 dB.
- **Case C: Same as Case B, except that**
  - The PFD level of each mission is set to –199.0 dBW/m^2/Hz for all elevation angles
- **Case D: Same as Case C, except that**
  - Victim receive antenna gains are all set to the same value: 57.5 dBi
- **Level of homogeneity increases from Case A to Case B to Case C to Case D**

Discussion of Preliminary Results

- The most interference is seen into missions #6 and #7, LANDSAT-7 and EO-1, and to a lesser degree, #3 and #4, AURA and AQUA. These pairs of missions use the same ground stations and have the same orbits, except that their right ascensions are separated by 0.25° and 2°, respectively. In effect, they are almost right on top of each other, causing large amounts of interference.
- The missions discussed immediately above exceed the ITU recommended sharing criteria in all cases. The other missions exceed the criteria in only a few cases.
- Homogeneity as modeled here has the effect of modifying the maximum interference levels seen, since the highest eirp density / PFD levels are reduced.
- Homogeneity also reduces the difference (spread) of interference levels seen among the various missions.
- The results of Cases C and D are very similar because the database victim receive antenna gains are very similar.

Degradation Relative to Best Case, Io Threshold = -197 dBW/Hz

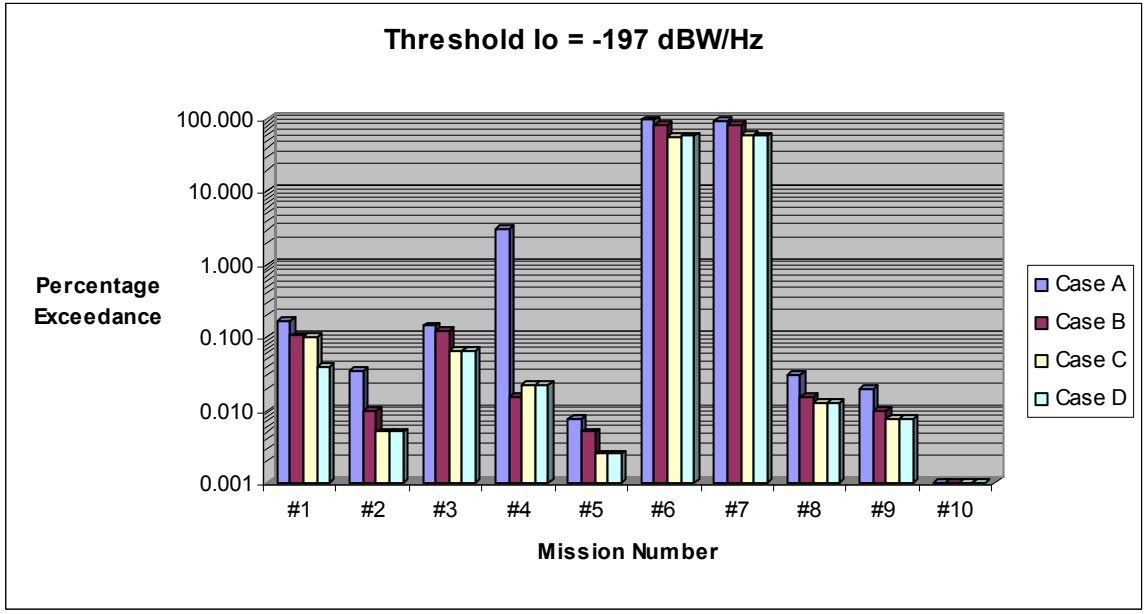
Improvement factor Γ_{iX}										
X \ i	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Case A	4.188	7.000	2.192	206.500	3.000	1.686	1.620	2.400	2.667	1.000
Case B	2.625	2.000	1.885	1.000	2.000	1.412	1.396	1.200	1.333	1.000
Case C	2.500	1.000	1.000	1.500	1.000	1.000	1.046	1.000	1.000	1.000
Case D	1.000	1.000	1.000	1.500	1.000	1.006	1.000	1.000	1.000	1.000

$$\Gamma_{iX} = \frac{P_{iX}(I > I_0)}{P_{iY}(I > I_0)}$$

i = mission number

$X = A, B, C, D$

Y = Best case



Degradation Relative to Best Case, Io Threshold = -201 dBW/Hz

Improvement factor Γ_{iX}										
X \ i	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Case A	1.610	4.100	1.097	1.392	1.200	1.072	1.072	2.083	2.143	1.000
Case B	1.130	1.300	1.062	1.057	1.000	1.072	1.071	1.000	1.000	1.000
Case C	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Case D	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

$$\Gamma_{iX} = \frac{P_{iX}(I > I_0)}{P_{iY}(I > I_0)}$$

i = mission number

$X = A, B, C, D$

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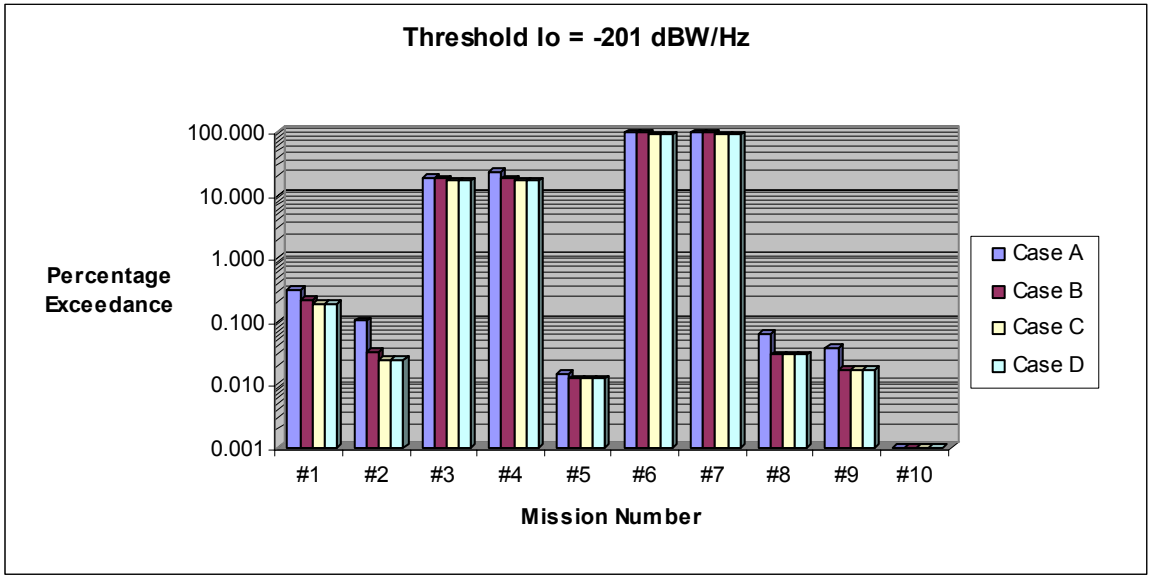


Degradation Relative to Best Case, Io Threshold = -207 dBW/Hz

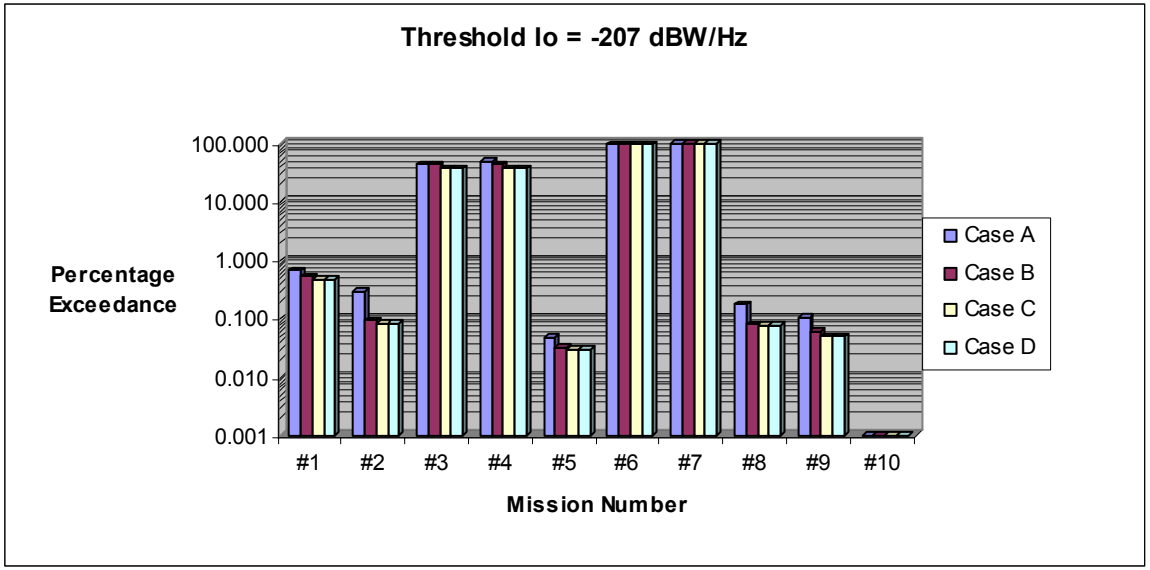
Improvement factor Γ_{iX}										
X \ i	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
Case A	1.414	3.576	1.190	1.327	1.583	1.000	1.000	2.226	2.100	1.000
Case B	1.140	1.152	1.170	1.171	1.083	1.000	1.000	1.032	1.200	1.000
Case C	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Case D	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000

$$\Gamma_{iX} = \frac{P_{iX}(I > I_0)}{P_{iY}(I > I_0)}$$

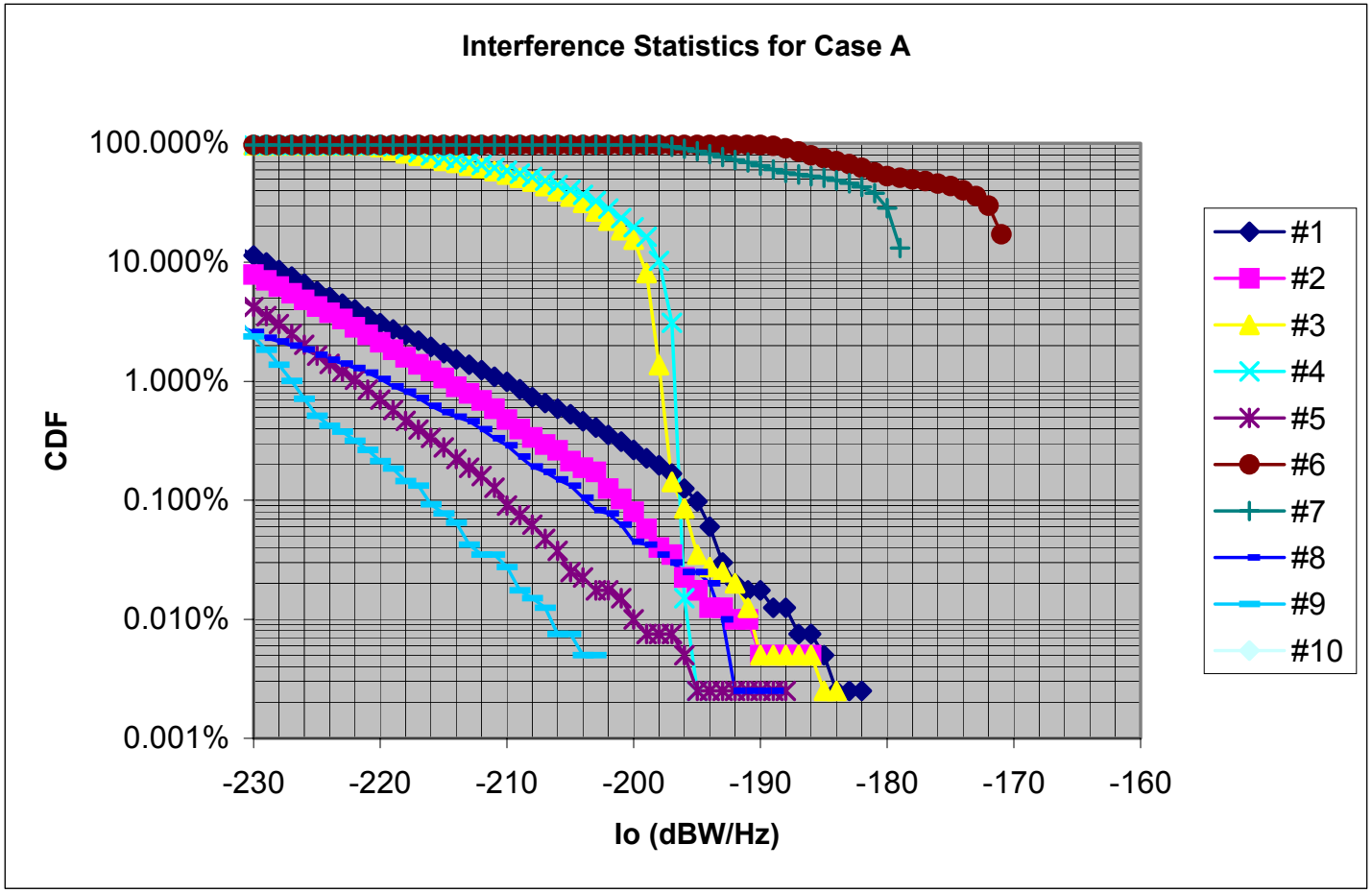
i = mission number

$X = A, B, C, D$

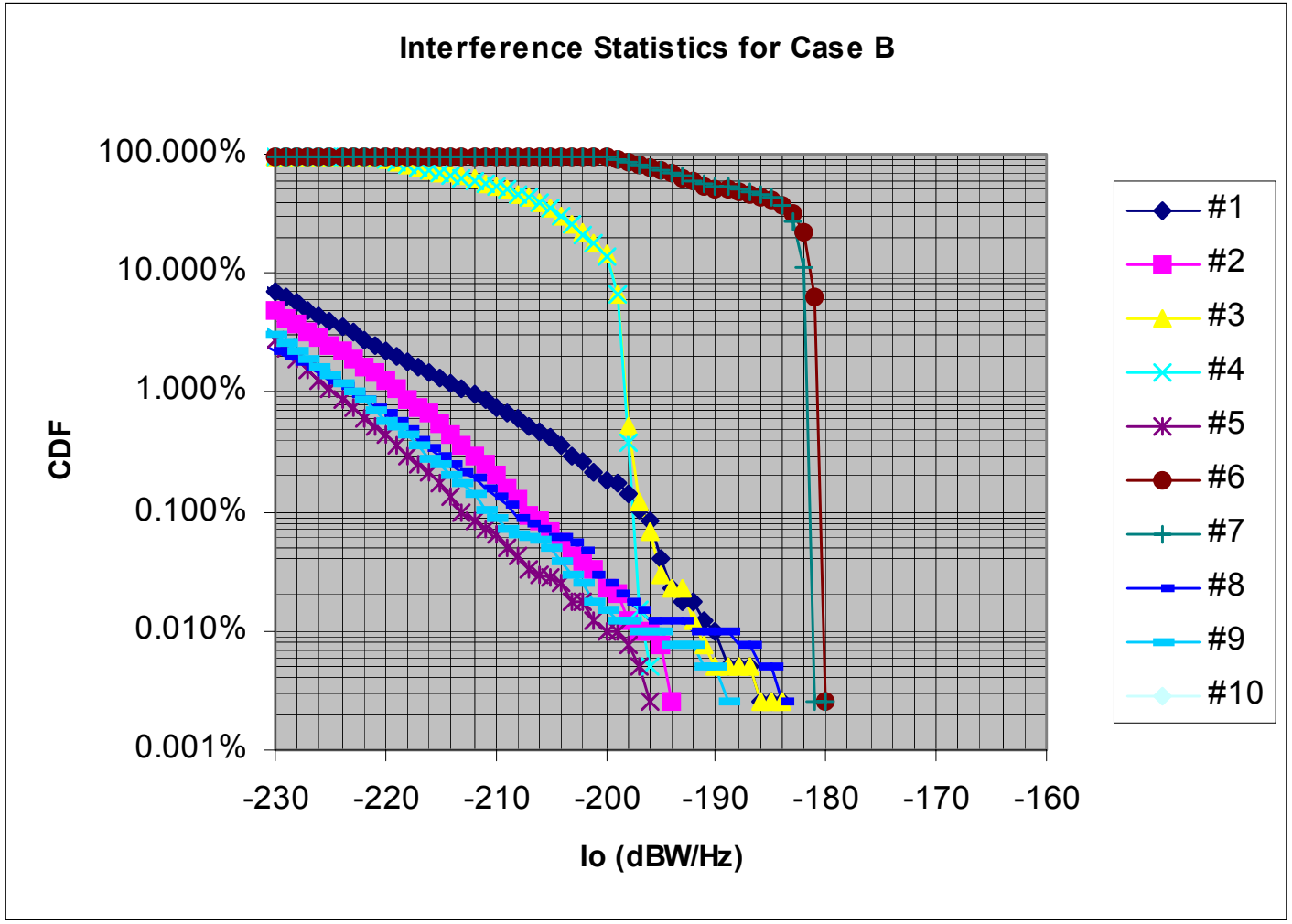
Y = Best case



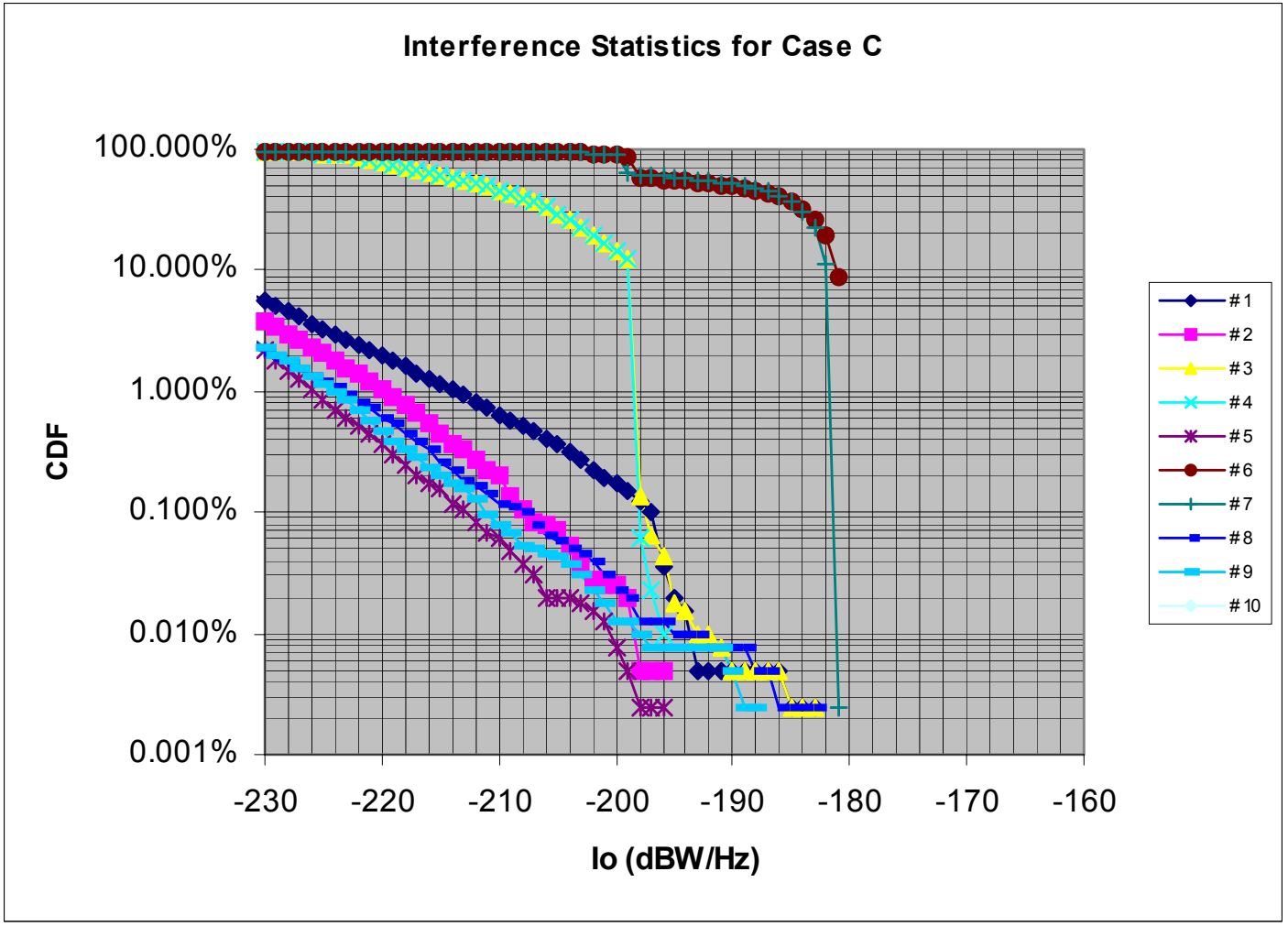
Results: Case A



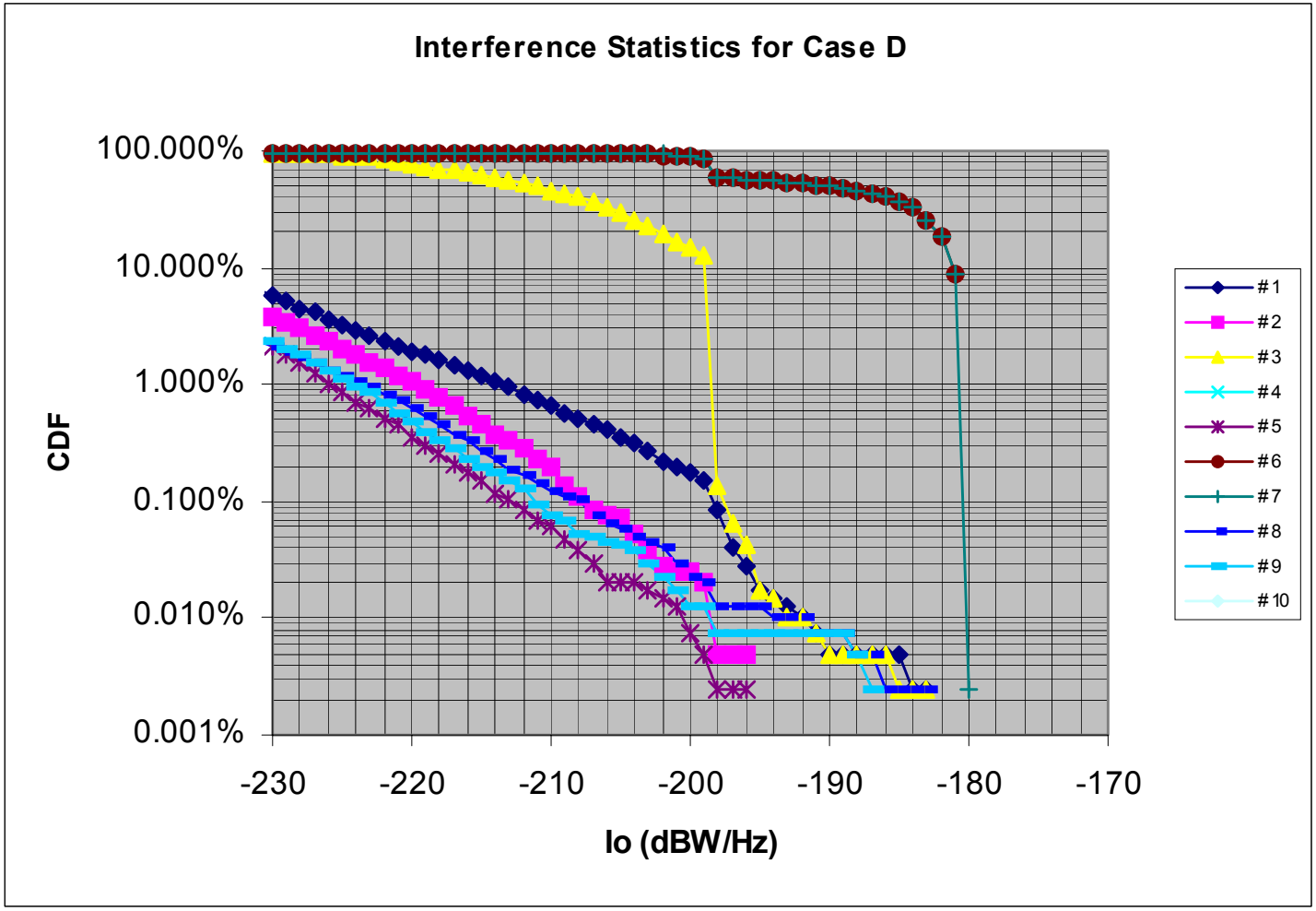
Results: Case B



Results: Case C



Results: Case D

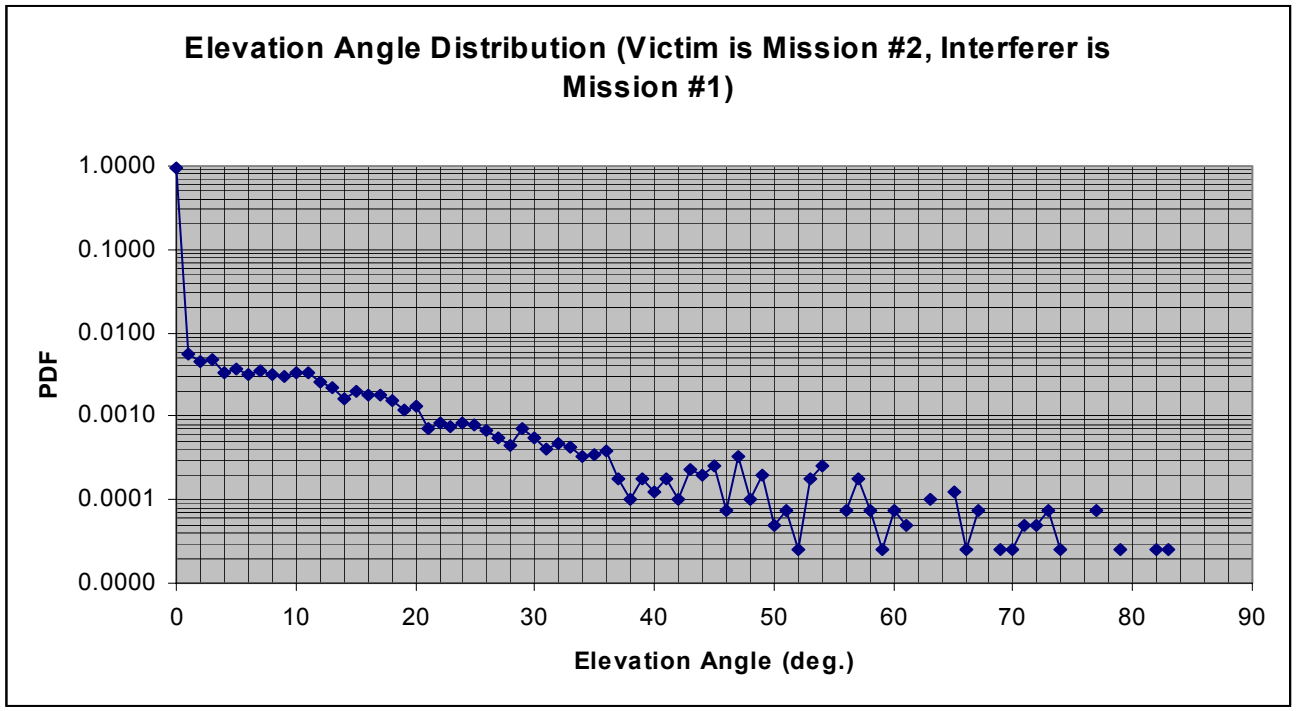


Conclusions from the NGSO Preliminary Study

- The goal of this preliminary study, as well as that of related future study, is to determine how to efficiently use this orbit/spectrum resource
- The following are the significant general results of this preliminary study
  - Homogeneity of missions' PFD levels does make a difference in terms of improving the sharing situation
  - Application of an iso-flux pfd provides additional improvement in the sharing situation
  - A factor that causes significant levels of interference to exist is having two co-orbiting satellites with very little orbital separation
- Future studies are planned to be performed using the results of this study as a baseline
  - Additional missions should be added to the analysis as their data become available
  - Other mitigation techniques, possibly including other types of homogeneity should be studied

Elevation Angle Distribution

- Victim is Mission #2: Ground Station is Poker Flats, AK (Lat = 64.8°N)
- Interferer is Mission #1: Alt is 705 km, incl is 98.08°
- Large proportion of elevation angles between 5° and 25°
  - Using an isoflux PFD in this range will result in improvement
  - See Cases B and C above



Results: Cases A - D